The influence of visual information on assessment of wind turbine noise

Anna Preis, Malina Szychowska, Honorata Hafke-Dys, Jędrzej Kociński
Institute of Acoustics, Adam Mickiewicz University, Poznań, Poland.

Summary

Current research into soundscape is carried out without taking into account the sense of sight. Nevertheless, there is no doubt that at the higher levels of the nervous system all the information coming from the different senses is merged together, integrated and analyzed. The aim of this paper is to examine the influence of visual information on wind turbine noise assessment. A set of 5 different soundscapes and 8 landscapes, including both views, of wind turbines and their noises, were recorded with an ambisonic microphone and high-definition video camera. The experiment took place in an anechoic chamber, appropriately adapted to present ambisonic recordings with a set up of 25+1 speakers arranged in a cubic form, and a large screen for video presentation. The experiment was divided into three parts, namely: auditory, visual, and audio-visual. In each part of the experiment the ICBEN scale (0-10) was used to rate the presented stimuli. In the first part, audio stimuli were presented randomly at 5 different levels: L_{Aeq} = 45, 50, 55, 60, 65 dB, and subjects were asked to rate the sound annoyance. Additionally, after that part of the experiment subjects were asked to listen again to the set of sounds and write the names of the identified (recognized) sound sources in each presented soundscape. In the second part of the experiment, participants were asked to rate how pleasant were the landscapes they were presented with.. Finally, in the last part of the experiment participants were presented with a compatible and incompatible mix of audio and visual stimuli and asked to rate the annoyance. Obtained results should provide an answer to the question of whether it is reasonable to analyze wind turbine noise without taking into account the sense of sight.

PACS no. 43.50.Qp, 43.66.Lj

1. Introduction

Research in the environmental acoustics and current legal standards regarding permitted noise levels and the distances from the noise sources do not take into consideration the sense of sight. Especially, it is common practice to link the noise annoyance only to the yearly averaged A-weighted day-evening-night equivalent level - LDEN. However, it is quite obvious that on the higher stages of nervous processing in the brain – information received from all of the senses is merged, integrated and analysed altogether. In a laboratory setting it is possible to almost completely eliminate information coming from one of the senses. Participants can wear earplugs, close eyes, or the experiment can be executed in the anechoic chamber. But in real life, a healthy person is never relying on one sense only. People are always receiving information from all the senses all the time, even if they are not always aware of that. What is more, the information from one sense can strongly influence the perception of the information from the other sense or even completely change the whole perceived event. This suggests that one should not restrict their research regarding noise annoyance to one modality only - hearing. Wind turbines are relatively new sound sources in the environment. Their noise is periodical, amplitude and frequency modulated, and although one would expect it to be really loud - wind turbines actually generate fairly low noise levels of approximately 40 dBA at the distance of 400 m. As a comparison – a regular refrigerator at a distance of 1m generates similar sound level as the wind turbine at 400 m. Nevertheless people living in vicinity of wind turbines often complain about how they are, more annoying than any other noise sources [1],[2]. Many research suggest, that besides loudness, the following factors influence the annoyance rating of wind turbines: periodicity [3], amplitude modulation [4], attitude towards wind turbines and money [5], and information from other senses [1],[2]. Furthermore, it was recently suggested that correct identification of a wind turbine in a presented auditory stimuli influences the resulting annoyance ratings [6].

In this study the interaction between sight and audition, and the influence of correct sound source identification on the noise annoyance are investigated. It is common practice in soundscape research to use questionnaires, distributed among people living close to wind turbines, to collect their ratings of noise annoyance. From these surveys it was suggested that the shape of the terrain and the type of the environment (rural, urban) influences the annoyance ratings, specifically that the annoyance increases when the wind turbine is placed on the flat terrain in a rural environment (when the wind turbine is clearly visible) [7]. However, these results cannot exclude the influence of the attitude towards the wind turbines, and the economic factors (e.g. people might think: "someone else is getting paid by having the wind turbine on his field and I am not").

In this study, participants were students that had no relation to the wind turbines, except seeing them from time to time, so their answers were not biased by the "money" (economical benefit) factor. Participants were presented with a set of 5 different soundscapes and 8 landscapes. Wind turbines were included in both sets of stimuli.. The stimuli were recorded with an ambisonic microphone and high-definition video camera. The experiment took place in an anechoic chamber, appropriately adapted to present ambisonic recordings by installing a setup of speakers arranged in a cubic form, and a large screen for video presentation. The system used made it possible to mimic real life environment in a laboratory setting. Experiment was divided into three parts: auditory, visual, and audio-visual. In the first part - **experiment 1** - audio stimuli were randomly presented at 5 different sound levels, and participants were asked to rate the noise annoyance. Additionally after that part subjects were asked to listen again to the set of sounds and identify the sound sources in every presented soundscape. In the second part - **experiment 2 -** participants were asked to rate the pleasantness of landscapes, which were shown to them on the video screen. Finally, in the last part-**experiment 3** - participants were presented with compatible and incompatible mixes of auditory and visual stimuli and asked to rate the annoyance of the entire environment.

Tested hypotheses were as follow:

- visual stimuli has a large effect on evaluating the annoyance of soundscapes,
- correct identification of wind turbine in the auditory stimulus increases the annoyance ratings,
- visibility of wind turbine increases the annoyance of the whole environment in both situations: when the wind turbine noise is present in the soundscape and when it is not.

Finally it was hypothesized that wind turbine noise annoyance should not be assessed without taking into account the sense of sight. Further exploration of this issue may in the future lead to a reconsideration of current legal standards regarding permitted noise levels and distances from noise sources.

2. Method

2.1. Subjects

Forty-five students (18 M, 27 F), with normal hearing and normal or corrected to normal vision took part in the experiment. The majority of the participants were not exposed to wind turbine noise on a daily basis at all, however several subjects did have an experience of hearing wind turbine noise at some point in their lives. All participants were provided with financial gratification for taking part in this study

2.2. Stimuli and equipment

Table 1 presents five different soundscapes/noises (20 sec duration, 10 ms fade-in/out) that were recorded and used in experiments 1 and 3. In the statistical analysis only auditory recordings of

Table 1. List of auditory stimuli.

Soundscape	Name	Description
Airplane	AP	DISTRACTOR Starting of an airplane close to the airport
Storm	ST	DISTRACTOR Sea during a very windy weather
Wind turbine	WTs	0.8 MW; recorded during day-time, wind speed 4-5 m/s at 10m above the ground (ICM Meteo), distance of 130 m.
2 MW wind turbine	WT1	2 MW; recorded during night-time, wind speed 3-4 m/s at 10m above the ground, between days when wind was blowing 5-7 m/s (ICM Meteo), distance of 130 m.
2 MW wind turbine	WT2	2 MW; Recorded during night-time, wind speed 3-4 m/s at 10m above the ground, between days when wind was blowing 5-7 m/s (ICM Meteo), distance of 50 m. One damaged blade.

wind turbines were used. Recordings of airplane noise and stormy sea were presented to participants only as distractors.

Eight different landscapes (20 sec duration, 10 ms fade-in/out) were recorded and used in experiments 2 and 3. Screenshots of all landscapes are presented in figure 1.

The experiment took place in the anechoic chamber in Adam Mickiewicz University in Poznań. It was appropriately adapted to present ambisonic recordings by installing a setup of 25+1 speakers (Yamaha HS50m) arranged in a cubic form and a high quality, quiet projector (NEC NP-PA500U), as well as a large, perforated (sound-permeable) screen for video presentation. For the duration of the experiment - the light in the anechoic chamber was turned off. The system used made it possible to mimic real life experience in a laboratory setting . Audio stimuli were recorded in a 4-channel B-format with first order ambisonics microphone – ST450 MKII SoundField Portable, and high quality recorder SQuadriga II HEAD Acoustics. Following the experiments obtained recordings were converted to a 26-channel file using custom written software. Visual stimuli were recorded with high definition camera Canon XF100.

To calibrate the system measurement microphone was placed in a position matching that of the head of the participant. Auditory stimuli were set to following sound levels: L_{AeqT} = 45, 50, 55, 60, 65 dB in the first experiment (only auditory presentation), and L_{AeqT} = 45, 55, 65 dB in the third experiment (audio-visual presentation).

2.2. Procedure

In the first experiment participants were asked to assess the annoyance of auditory stimuli on the standardized ICBEN scale (0-10) where 0 was not annoying at all and 10 - extremely annoying. Participants were presented with 5 different soundscapes at 5 sound levels (L_{AeqT} = 45, 50, 55, 60, 65 dBA). Each stimulus was repeated 3 times. Subsequently - participants were once again presented with the 5 auditory stimuli at sound level equal 55 dBA and asked to identify sound sources of presented stimuli.

In the second experiment participants were asked to assess the pleasantness of visual stimuli on the standardized ICBEN scale (0-10) where 0 was not pleasant at all and 10 - extremely pleasant. Participants were presented with 8 different landscapes. Each stimulus was repeated 3 times.

In the third experiment participants were asked to assess the annoyance of the mixture of auditory and visual stimuli on the standardized ICBEN scale (0-10) where 0 was not annoying at all and 10 - extremely annoying. Participants were presented with a mixes of 5 different soundscapes at 3 sound levels (L_{AeqT} = 45, 55, 65 dB) and 8 landscapes. The sound of the washing machine was not used in this part of the experiment. Not all possible combinations were presented, only the ones that were making the most sense. The recordings of wind turbines' views and noises were combined with all possible stimuli. This resulted in 111 audio-visual samples. Each sample was repeated 3 times.

Figure 1. Screenshots of the visual stimuli.

3. Results

3.1. Experiment 1

Results of independent t-tests indicated that the difference between responses of subjects who have correctly identified the wind turbine noise and those who did not, averaged across sound levels, was statistically significant for WTs (t=5.31, d=0.86, p<0.01), WT2 (t=5.65, d=0.80, p<0.01), but not for WT1 (t=1.05, d=0.04, p<0.01). Nevertheless, a clear trend of increased annoyance rating when the wind turbine is correctly identified can be seen in all of the experimental conditions (Figure 2).

Furthermore, for samples WTs and WT2, there is a difference of approximately 10 dB for the same annoyance rating, between people who did not correctly identify the sound source to be a wind turbine as opposed to those who did. These results support the Cohen's d values, suggesting big effect sizes for this comparison. Another independent t-test analysis revealed significant differences between two groups for each of the sound level separately for WTs (p<0.05) and WT2 (p<0.05) but not a single case for WT1.

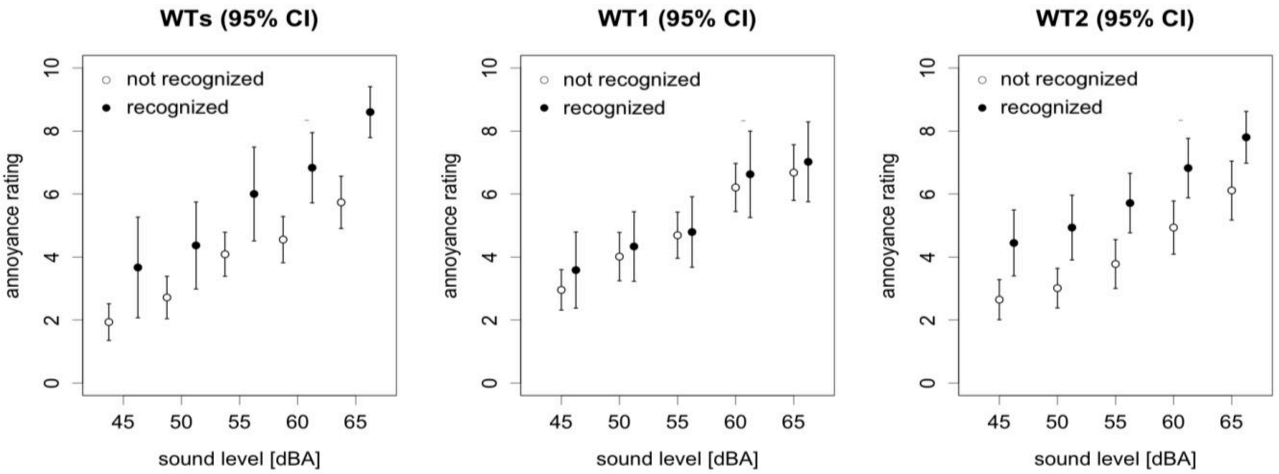

Figure 2. Source identification

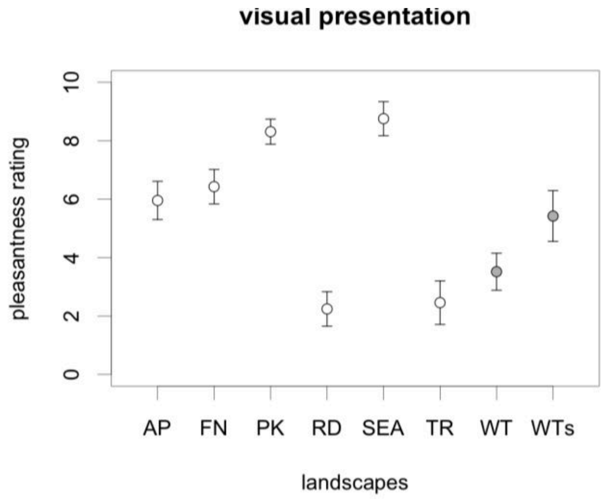

Figure 3. Pleasantness ratings for visual stimuli.

3.2. Experiment 2

Results of the second experiment confirmed that sea was perceived as the most pleasant environment, while road and train were rated as the least pleasant as seen in Figure 3. Results of this experiment were mostly used as a point of reference for the third experiment

3.3. Experiment 3

One-way ANOVA revealed that both: type of the video ($p<0.01$ for all audio recordings, $\eta^2_{WTs}=0.05$, $\eta^2_{WT1}=0.07$, $\eta^2_{WT2}=0.07$) and sound level ($p<0.01$ for all audio recordings, $\eta^2_{WTs}=0.26$, $\eta^2_{WT1}=0.27$, $\eta^2_{WT2}=0.26$) are statistically significant when assessing annoyance of wind turbine.

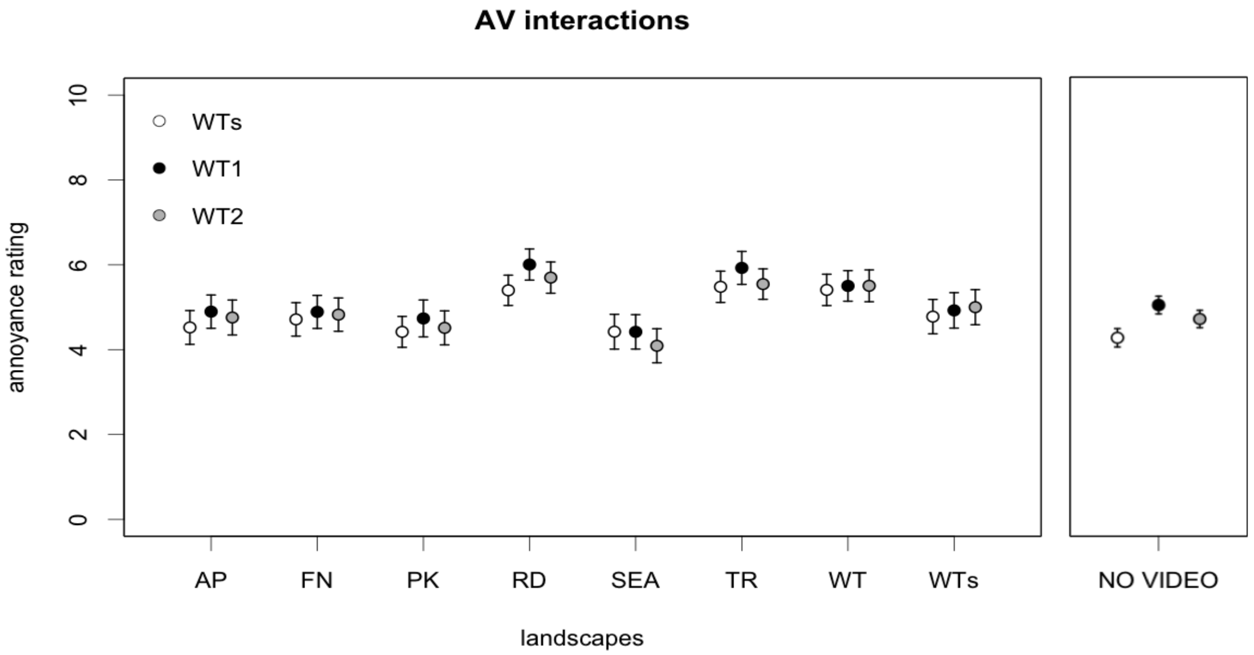

Figure 4. Audio (WTs, WT1, WT2) with different Video.

Table 2. Statistically significant results of t-test comparing auditory only and audio-visual stimuli.

V:	A: WTs t	Cohen's d	WT1 t	Cohen's d	WT2 t	Cohen's d
NO_VID vs. RD	4.52**	0.50	3.90**	0.43	4.00**	0.44
NO_VID vs. TR	4.77**	0.53	3.47**	0.38	3.41**	0.38
NO_VID vs. SEA	0.56	0.06	2.35*	0.26	2.38*	0.26
NO_VID vs. WT	4.48**	0.49	1.90	0.21	3.08**	0.34
** p<0.01 * p<0.05						

From figures 3 and 4 it is visible that videos rated as the most pleasant and unpleasant had the biggest effect on the assessment of wind turbines annoyance. Independent t-test revealed significant differences between ratings of the auditory stimuli alone and several audio-visual combinations. Results are presented in table 2.

4. Conclusions

Based on the results of this study it can be suggested that, although it is not statistically significant for all the samples, there is a visible trend of assessing wind turbines as more annoying when their presence is recognized in the soundscape. The fairly large effect sizes for the stimuli WTs and WT2 could be presented with a physically measured value of approximately 10 dBA. What is more, this study confirmed, in an almost "real life" environment (large screen and the ambisonic system in the anechoic chamber), previously published results [1],[7], which stated that visual information has an influence on the assessment of wind turbines annoyance, especially when it comes to landscapes rated extremely pleasant or unpleasant. Visual stimuli rated highest on the pleasantness scale tended to make the wind turbine noise less annoying, whereas visual stimuli that were rated less pleasant – tended to increase the perceived annoyance of wind turbines. Furthermore a comparison between the ratings for no video and WT video suggests that the annoyance rating increases when wind turbines are visible.

Acknowledgement

This research was supported by a grant from National Science Centre:
Project Number UMO-2011/03/B/HS6/03709.

References

[1] S.A. Janssen, H. Vos, A. Eisses, E. Pedersen: A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. Journal of the Acoustical Society of America (2011), 130(6): 3746-3753.

[2] E. Pedersen, K. P. Waye: Perception and annoyance due to wind turbine noise – a dose response relationship. Journal of the Acoustical Society of America (2004), 116(6): 3460–70.

[3] A. Bockstael, L. Dekoninck, A. Can, D. Oldoni, B. De Coensel, D. Botteldooren: Reduction of Wind Turbine Noise Annoyance, An Operational Approach. Acta Acustica united with Acustica (2012), 98: 392-401.

[4] S. Lee, K. Kim, W. Choi: Annoyance caused by amplitude modulation of wind turbine noise. Noise Control Engineering (2011), 59: 38–46.

[5] E. Pedersen, F. van den Berg, R. Bakker, J. Bouma: Response to noise from modern wind farms in The Netherlands. Journal of the Acoustical Society of America (2009), 126: 634–43.

[6] T. Van Renterghem, A. Bockstael, V. De Weirt, D. Botteldooren: Annoyance, detection and recognition of wind turbine noise. Science of the Total Environment (2013), 456-457: 333-345.

[7] E. Pedersen, P. Larsman: The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. Journal of Environmental Psychology (2008), 28(4): 379-389.